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PERFORMANCE ANALYSIS OF OPTICAL OFDM SYSTEM USING PM

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ABSTRACT

As the demand of new wireless telephony applications grow exponentially and interest in discovering various methods to combat interference and provide solutions broadband wired and wireless communication system. Orthogonal frequency division multiplexing (OFDM) is considered to as one of the promising solution for such applications as well as a strong contestant modulation technique for fiber optical communication. This paper highlights multi-dimensional while considering fiber optic communication with OFDM. To achieve good performance in optical systems, OFDM must be adapted in various ways. This paper gives the performance analysis of optical orthogonal frequency division multiplexing using phase modulation (PM) technique with optical fiber link. Our study shows that as the length of the fiber increases the distortion also increases. This distortion can be decreased with the help of Raman amplifier.

KEYWORDS: CO-OFDM, Cyclic Prefix, Opt SIM, Phase Modulation, QAM

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a special class of multicarrier modulation. It is used extensively in broadband wired and wireless communication systems because it is an effective solution to inter-symbol interference (ISI) caused by a dispersive channel [1-6]. This becomes increasingly important as data rates increase to the point where, when conventional serial modulation schemes like quadrature amplitude modulation (QAM) or non-return to zero (NRZ) are used, the received signal at any time depends on multiple transmitted symbols [7-10]. In this case the complexity of equalization in serial schemes which use time domain equalization rises rapidly. In contrast, the complexity of OFDM, and of systems using serial modulation and frequency domain equalization, scale well as data rates and dispersion increase. A second major advantage of OFDM is that it transfers the complexity of transmitters and receivers from the analog to the digital domain. For example, while the precise design of analog filters can have a major impact on the performance of serial modulation systems, in OFDM any phase variation with frequency can be corrected at little or no cost in the digital parts of the receiver [11-14].

The properties of the equivalent baseband channel and the noise reduction algorithm are explained in more detail [15]. The performance of an adaptive decision-directed channel equalizer in reduced-guard interval dual-polarization coherent-optical orthogonal frequency division multiplexing (RGI-DP-CO-OFDM) transport systems is given. A Coherent Optical OFDM (COOFDM) system using Differential phase shift keying (DPSK) for data rate 16Gbits/s is implemented in at the bit-error-rate (BER) of 9.8×10^{-12}.

While many details of OFDM systems are very complex, the basic concept of OFDM is quite simple. The data is transmitted in parallel on a number of different frequencies, and as a result the symbol period is much longer than for a serial system with the same total data rate. Because of the symbol period is longer, ISI affects at most one symbol,

and equalization is simplified. In most OFDM implementations any residual ISI is removed by using a form of guard interval called a cyclic prefix [16].

When frequency division multiplexing (FDM) is used in conventional wireless systems, or wavelength division multiplexing (WDM) is used in optical systems, information is also transmitted on a number of different frequencies simultaneously. However, there are a number of key theoretical and practical differences between OFDM and these conventional systems. In OFDM the subcarrier frequencies are chosen so that the signals are mathematically orthogonal over one OFDM symbol period. Both modulation and multiplexing are achieved digitally using an inverse fast Fourier transform (IFFT) and as a result, the required orthogonal signals can be generated precisely and in a very computationally efficient way. In FDM/WDM there are frequency guard bands between the subcarriers. At the receiver the individual subcarriers are recovered using analog filtering techniques. The below Figure 1 shows spectra for FDM/WDM and OFDM. In OFDM the spectra of individual subcarriers overlap, but because of the orthogonality property, as long as the channel is linear, the subcarriers can be demodulated without interference and without the need for analog filtering to separate the received subcarriers. Demodulation and demultiplexing is performed by a fast Fourier transform (FFT). The spectrum of an individual OFDM subcarrier has a $|\sin(x) / x|^2$ form, so each OFDM subcarrier has significant side lobes over a frequency range which includes many other subcarriers. This is the cause of one of the major disadvantages of OFDM: that it is quite sensitive to frequency offset and phase noise [17 -18].

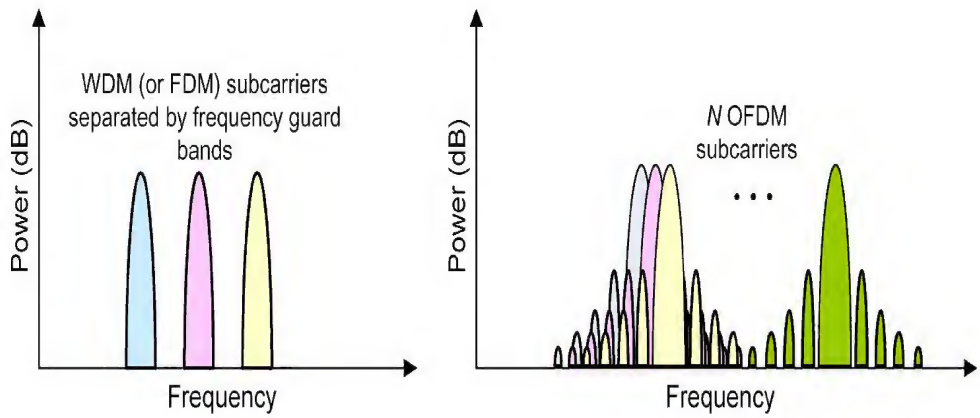


Figure 1: Spectrum of (a) WDM or FDM Signals (b) OFDM Signal

In this paper, we present optical application of OFDM using coherent detection. Section 2 describes basic elements of OFDM system for wireless communication. An experimental setup, in section 3, The parameters used and simulation results are discussed in section 4. Finally the conclusions presented in section 5.

2. OFDM SYSTEM DESCRIPTION

In this session a typical OFDM system for wireless applications is described. A method to remove frequency selective fading is described in section 2.1. After coding and interleaving data is mapped onto complex numbers representing the QAM constellation being used for transmission. The sequence of complex numbers output from the constellation mapping are then serial-to-parallel (S/P) converted to form a vector suitable for input to the IFFT. Description of IFFT and FFT is given in 2.2. The sequence of symbols after adding cyclic prefix is given in 2.3. Transmitter and receiver front ends are described in 2.4.

2.1 Coding Interleaving and Mapping

The first blocks in the transmitter are interleaving and coding.All OFDM systems use some form of error correction or detection because, if there is frequency selective fading in the channel, some of the parallel data streams will experience deep fading. The coding is usually preceded by interleaving because; a number of adjacent OFDM subcarriers may fall within the frequencies which are experiencing fading. In most broadcast applications of OFDM such as digital audio broadcasting (DAB) and digital video broadcasting (DVB) there are two layers of interleaving and coding so that a very low overall bit error rate (BER) can be achieved even over a very noisy channel. After coding, the data is mapped onto complex numbers representing the QAM constellation being used for transmission. Constellation sizes from 4 QAM to 64 QAM are typically used. While phase shift keying (PSK) is compatible with OFDM, it is rarely used. PSK in OFDM, unlike PSK in single carrier systems, does not have a constant signal envelope and, for large constellations, has smaller distance between constellation points and so is more susceptible to noise. The sequence of complex numbers output from the constellation mapping are then serial-to-parallel (S/P) converted to form a vector suitable for input to the IFFT.

2.2 FFT and IFFT Technique

The IFFT and FFT are the main components in the transmitter and receiver. These are the functions which distinguish OFDM from single carrier systems. The input to the IFFT is the complex vector as equation (1).

$$X = [X_0\ X_1. . .X_{N-1}]^T \tag{1}$$

The vector has length where N is the size of the IFFT. Each of the elements of X represents the data to be carried on the corresponding subcarrier. Usually QAM modulation is used in OFDM, so each of the elements of X is a complex number representing a particular QAM constellation point. The output of IFFT is a complex vector as equation (2).

$$x = [x_{0,}\ x_1.\ x_{N-1}]^T \tag{2}$$

The main advantage in using FFT/IFFT is that the discrete signals at the input and the output of the transform for each symbol have the same total energy and same average power. The signals at the input and the output of the IFFT are for 16- QAM modulation and N = 16. The output is the corresponding time domain vector x. For $N \geq 64$ the real and imaginary components of an OFDM time domain signal are approximately Gaussian. For wireless OFDM systems which have already been standardized, values of N ranging from 64 in wireless LAN systems to 8096 in digital television systems have been used. At the receiver the FFT performs a forward transform on the received sampled data for each symbol. The vector representing the sampled time domain signal at the input to the receiver FFT is equation (3).

$$y = [y_0\ y_1\ y_2 . . . y_{N-1}]^T \tag{3}$$

and the discrete frequency domain vector at the FFT output equation (4).

$$Y = [y_0\ y_1\ y_2 . . . y_{N-1}]^T \tag{4}$$

N is the samples are required per OFDM symbol (excluding CP).

2.3 Cyclic Prefix

The IFFT generates each OFDM symbol. The transmitted signal consists of a sequence of these OFDM symbols. To denote different OFDM symbols when a sequence of symbols rather than a single symbol is being considered, we need to extend the notation to include a time index. Let $x(i) = [x_0(i)x_1(i) . . . . x_{N-1}(i)]^T$be the output of IFFT in the i^{th}

symbol period. In most OFDM systems, a cyclic prefix (CP) is added to the start of each time domain OFDM symbol before transmission. In other words a number of samples from the end of the symbol are appended to the start of the symbol. So instead of transmitting $x(i) = [x_0(i)x_1(i) \ldots x_{N-1}(i)]^T$ the sequence is transmitted; where is the length of the cyclic prefix. Although the CP introduces some redundancy, and reduces the overall data rate, the use of the CP eliminates both ISI and inter carrier interference (ICI) from the received signal and is the key to simple equalization in OFDM. When a CP is used, any distortion caused by a linear dispersive channel can be corrected simply using a single-tap equalizer. For the case where OFDM transmission is at pass band, the gains and the signals will be complex; for the case of baseband transmission the gains and signals are real. As long as the start of the receiver time window is aligned with the start of the "main" OFDM symbol of the first arriving signal, and if the delay spread is less than the length of the CP, there is no inter symbol interference. The signal received in the i^{th} time window depends only on the i^{th} transmitted symbol.

$$x_{CP}(i) = [x_{N-G}(i) \ldots x_{N-1}(i), x_0(i) \ldots x_{N-1}(i)]^T \quad (5)$$

2.4 OFDM Transmitter and Receiver Front End

Figure 2 shows a block combining filtering, parallel-to-serial conversion (P/S) and digital-to-analog conversion (D/A) because in practice there is some choice about the order of these processes. For example, OFDM symbols are often windowed (a form of time variant filtering) to reduce the side lobes, sometimes the digital signal is up sampled before D/A conversion to simplify the analog filtering, and filtering can be in the analog or digital domain. However after this process the signal x(t) is an approximately band limited signal consisting of sinusoids of the baseband subcarrier frequencies. In wireless OFDM systems x(t) is a complex signal which forms the input to an IQ modulator for up conversion to the carrier frequency. For an OFDM system to work successfully the system must be (approximately) linear between the transmitter IFFT input and the receiver FFT output.

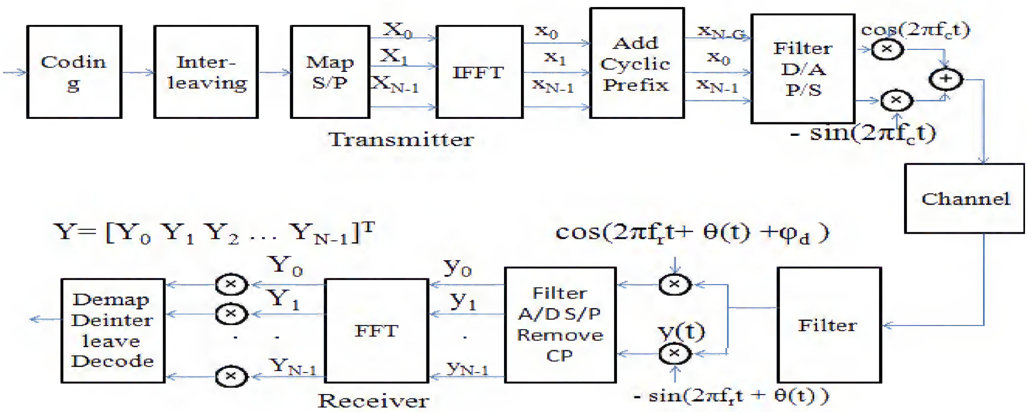


Figure 2: Basic Block Diagram of OFDM System with Transmitter and Receiver

3. EXPERIMENTAL SET UP

In this section an experimental set up used in the simulation and results obtained are described. The performance of an OFDM system for optical communication is analyzed by using OptSIM. Ophmod: Optical Phase Modulator, Ointerf: Optical Interferometer

OFDM modulation uses orthogonal carriers to transport the phase and amplitude information of multiple low-rate bit sequences modulated using BPSK, QPSK or QAM. Serial-to-parallel and parallel-to-serial conversions enable to transmit and receive a single high-rate bit stream.

The Opt SIM OFDM modulation models are several discrete blocks that can be combined with filters and noise sources to simulate realistic OFDM system setups. Moreover the signal can be monitored at each stage of the modulation process, making them ideal to study the modulation behavior details. Figure 3 shows an OFDM system using phase modulation. In the transmitter, a single 10 Gbit/s pseudo- random bit sequence is converted into a number of lower rate bit sequences controlled by the symbol modulation. In the transmitter, a single 10 Gbit/s pseudo-random bit sequence is converted into a number of lower rate bit sequences controlled by the symbol QAM_bit_number. In fact the multiplicity of the serial-to-parallel conversion corresponds to the number of bits to encode one QAM symbol. An intermediate binary to gray-code conversion is used in the modulation process. QAM constellations are obtained at QAM modulator. Here 16-QAM is used. Next the model IFFT OFDM converts the QAM symbols in OFDM symbols with an IFFT operation using a number of subcarriers controlled by the symbol subcarriers number, both accepting in input and returning on output baseband in-phase and in-quadrature signals.

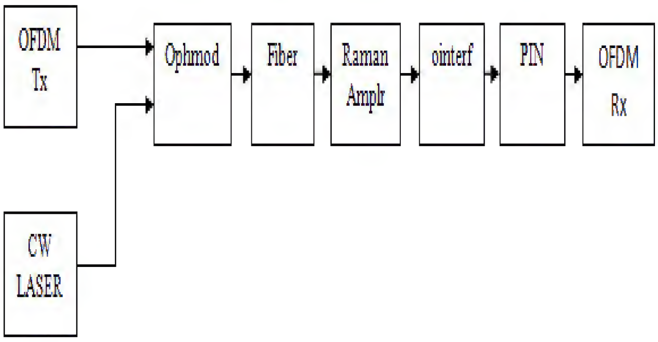


Figure 3: Experimental Set up Used for Simulation

After phase modulator fiber is connected. On the receiver side, before the signal is given to optical interferometer first. It converts the phase deviation in amplitude deviation to be detected with photo detector. The RF signal is translated to baseband with a quadrature mixing down conversion. The replica at twice the carrier frequency originated by the down conversion process is filtered out using two 7-pole low-pass Bessel filters centered at the carrier frequency, 10 GHz in this example. Finally the model FFT OFDM extracts the transmitted QAM symbols from the OFDM signal at baseband with an FFT operation.

4. SIMULATION RESULTS AND DISUSSIONS

The OFDM modulation is very sensitive to the sampling instant at the receiver. Not sampling the OFDM symbol at the optimum sampling instant results in very fast deterioration of the system performance. For this reason the OptSIM models IFFT OFDM and FFT OFDM include the option to use a training sequence to automatically find the optimum sampling instant. Moreover the model FFT OFDM can also automatically recover the amplitude and phase of the original QAM symbols, thus facilitating the demodulation into bit streams of the received QAM signal. Figure 4 shows the received QAM constellation with controlling automatic synchronization and amplitude/gain recovery. Finally the received QAM

symbols are converted into low-rate parallel bit streams and into a single high-rate bit sequence with a parallel-to-serial conversion.

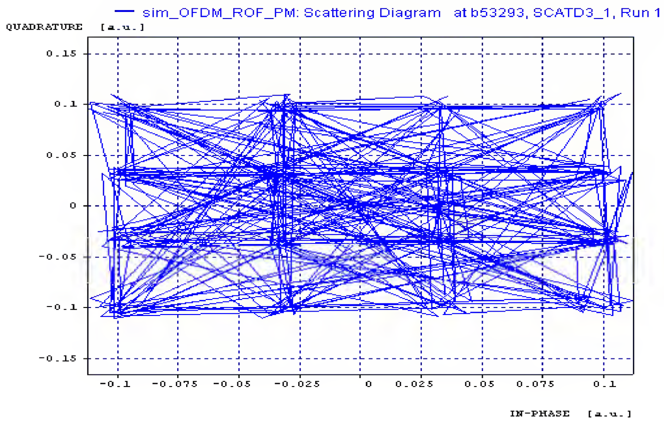
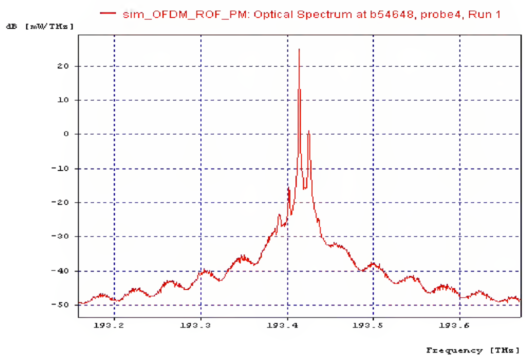
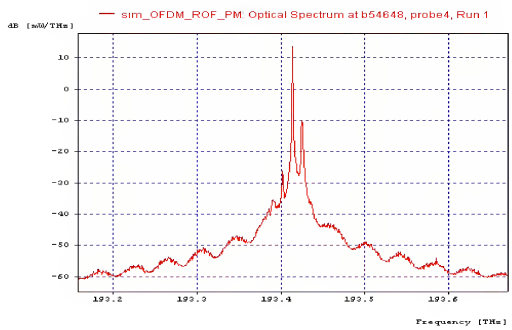


Figure 4: 16-QAM Received Constellation with Automatic Synchronization

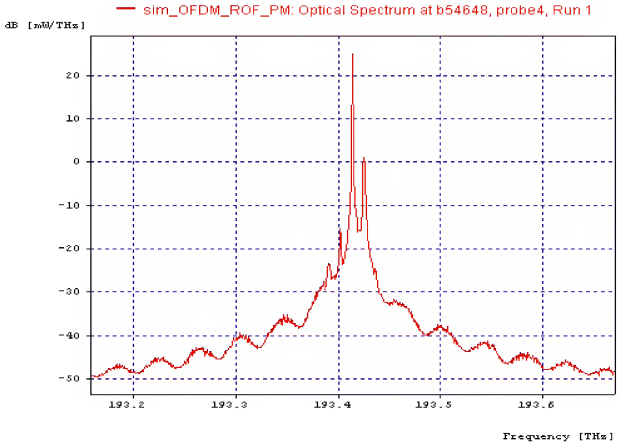
The length of the fiber is kept at 10 km first and then it is varied. At each stage when the fiber length is varied output is compared with the previous output. It is observed that as the length of the fiber increases the distortion also increases. This distortion can be decreased with the help of Raman amplifier. Figure 5 shows the power spectrum at the output of the OFDM transmitter after applying fiber for fiber length 10 km, 100 km without Raman amplifier and 1200 km after applying Raman amplifier. From figure it is observed that when the length of the fiber is increased at 100 km without applying any amplifier the power level of the spectrum is decreased by 10 dB and also the distortion is increased. When the Raman amplifier is applied the length of the fiber can be increased up to 1200 km without decrease in power level and with very less distortion. The properties of Raman amplifier help to reduce the distortion and noise in the output.



(a)



(b)



(c)

Figure 5: Power Spectrum after Applying Fiber at (a) Fiber Length = 10 Km, (b) Fiber Length = 100 Km Amplifier, (c) Fiber Length = 1200 Km with Raman Amplifier

5. CONCLUSIONS

In this paper, we have first reviewed the theoretical fundamentals for OFDM. A typical OFDM transmitter and receiver are described and the roles of the main signal processing blocks explained. It is shown that if a cyclic prefix is added to each OFDM symbol, any linear distortion introduced by the channel can be equalized. As the length of fiber increases the distortion gets added to it. Also the power level is decreased. This can be avoided with the use of Raman amplifier and the length of the fiber can be increased without decrease in power level and very less distortion and noise in the output.

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